Comparative Effects of 1BL.1RS and 1AL.1RS on Soft Red Winter Wheat Milling and Baking Quality

Anne L. McKendry,* David N. Tague, and Kathleen Ross

ABSTRACT

The wheat (*Triticum aestivum* L.)–rye (*Secale cereale* L.) chromosomal translocations 1BL.1RS and 1AL.1RS are widely reported to have detrimental effects on hard wheat quality. This study was designed to investigate the impact of these translocations on soft wheat milling and baking quality where information on their effects is limited. A set of backcross-six F_2-derived F_6 near-isolines containing either the 'Kavkaz'-derived 1BL.1RS or 'Amigo'-derived 1AL.1RS translocation were developed in five soft red winter wheat backgrounds at Columbia, MO. A randomized complete block design, replicated four times, was grown in each of three Missouri environments. Treatments were arranged as a split-plot with genetic background as the main-plot factor and isolines as the subplots. Both the presence of rye and the source of the translocation (1BL.1RS vs. 1AL.1RS) were significant for all traits measured. 1BL.1RS was associated with a significant reduction in softness equivalent but had no overall effect, across backgrounds, on adjusted flour yield or milling quality, while 1AL.1RS was associated with significant reductions in all three traits. Both translocations were associated with reduced baking quality due to their association with increased alkaline water-retention capacity and reduced kernel softness. For all traits the negative effect of 1AL.1RS was more pronounced than that of 1BL.1RS. Background interaction effects were significant for both milling-quality and baking-quality traits, and often were large enough to offset the negative effects associated with the translocation. This suggested that breeders could develop soft red winter wheat cultivars carrying either translocation that had acceptable end-use quality.

THE INTROGRESSION OF RYE GENETIC MATERIAL into the wheat genome through the use of wheat–rye chromosomal translocations has enhanced variability in wheat breeding programs worldwide. Two translocations, both involving the short arm of chromosome one in rye (1RS), have had the greatest commercial impact on the wheat industry, providing breeders with genes for wide adaptation, disease resistance, and enhanced grain yield (Zeller and Hsam, 1984; Lukaszewski, 1990; Rajaram et al., 1990; Rabinovich, 1998). The 1BL.1RS translocation, originally derived from 'Petkus' rye has been introduced into hundreds of wheat cultivars worldwide through the Russian wheat cultivars 'Kavkaz', 'Aurora', and their derivatives (Rajaram et al., 1990; Rabinovich, 1998). The 1AL.1RS translocation, originally derived from 'Insave' rye, was first introduced into hard red wheat cultivars through the germplasm line 'Amigo' and has been used primarily in North America and Australia (Lukaszewski, 1990; Martin and Stewart, 1990; Rabinovich, 1998). Other translocations including 1BS.2RL, 6BS.6RL, and 1DL.1RS are less common, having been used predominantly in wheat programs in the USA and Australia (Koebner and Shepherd, 1988; Rabinovich, 1998).

The primary hindrance to wider use of the 1BL.1RS and 1AL.1RS translocations is their well-documented adverse effect on hard wheat quality (Pena et al., 1990; Graybosch et al., 1993; Lee et al., 1995; Hussain et al., 1997). Doughs derived from bread wheat cultivars carrying this segment appear to have undesirable rheological properties that pose problems in mechanical processing (Law and Payne, 1983; Moonen and Zeven, 1984; Martin and Stewart, 1986). They are often sticky, with reduced dough strength and an intolerance to overmixing (Dhaliwal et al., 1987; Graybosch et al., 1993; Fenn et al., 1994). Dough stickiness has also been reported in cultivars with 1AL.1RS from Amigo (Martin and Stewart, 1990; Graybosch et al., 1993); however, Graybosch et al. (1993), in a comparative study of 1BL.1RS and 1AL.1RS flours, found the effects of 1AL.1RS to be less severe than those of 1BL.1RS.

Although reports of adverse effects of 1RS on hard wheat quality are common, there is a growing body of literature indicating that the genetic background into which the translocation is placed is critical to determining the effect on quality. Both Graybosch et al. (1993) and Fenn et al. (1994) reported a wide variation in dough stickiness across genetic background, and Hussain et al. (1997) found that specific changes in dough properties of 1BL.1RS lines depended on the high molecular weight glutenin subunit allele composition of the genetic background. They further suggested that the selection for specific subunits may ameliorate the damaging effects of this translocation on the physical performance of the dough.

The applications of soft wheat are very different from hard wheat, as are the testing criteria by which quality is determined. Results from hard wheat therefore have limited value for predicting how 1BL.1RS will impact soft wheat quality. Soft red winter wheat is commonly used in chemically leavened products including cookies, cakes, crackers, and biscuits; in yeast-leavened products such as saltines, pretzels, and flat breads; and in nonbaked products including soups and batters (Hoseney et al., 1988). In general, low to medium protein content, low water absorption, a high degree of kernel softness, and fine flour granulation are important traits for most soft wheat–based products (Finney, 1990). For chemically leavened products, full gluten development is avoided to produce a tender product. For yeast-leavened soft wheat products, flours with short mixing re-

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Abbreviation: AWRC, alkaline water-retention capacity.

quirements and weak gluten properties are desirable (Finney, 1990).

There are only two known reports of the effects of 1BL.1RS and no known studies of the effects of 1AL.1RS on soft wheat quality. McKendry et al. (1996) reported that 1BL.1RS was associated with a significant reduction in adjusted flour yield and overall milling quality in two genetic backgrounds. Although alkaline water-retention capacity (AWRC) was increased in translocation backgrounds, the study failed to detect significant differences between sister lines for overall baking quality. Johnson et al. (1999) examined 10 soft red winter wheat lines, 6 with the 1BL.1RS translocation and 4 without the translocation, and found mean flour yield, grain protein, and rheological properties of the dough to be similar for both groups. In a direct comparison of sister lines with and without the translocation, however, flour yield was reduced in 1BL.1RS lines. The effect of the translocation on baking quality was related to the baking test used. A significant reduction in cookie diameter was associated with the translocation, but cake volume appeared to be unaffected. Consistent with McKendry et al. (1996), the effect of genetic background was highly significant, affecting milling and baking quality to a greater extent than the translocation. Results suggested that negative effects of 1BL.1RS could be offset by selection within genetic backgrounds with good milling and baking quality.

To evaluate the effects of 1BL.1RS on milling and baking quality, McKendry et al. (1996) used sister lines while Johnson et al. (1999) used different genotypes with or without the translocation. In both studies, the confounding effect of genetic background could be highly significant. The use of near-isolines should eliminate these background effects, thereby permitting evaluation of the effects of the translocation independent of the background into which it has been placed. The objective of this research was to investigate the effects of both 1BL.1RS and 1AL.1RS on milling and baking quality in soft red winter wheat through the use of near-isolines. A secondary objective was to evaluate the magnitude of the effect of genetic background to determine whether any negative effects associated with these translocations could be ameliorated by selection in genetic backgrounds with good quality.

MATERIALS AND METHODS

Germplasm Development

Backcross-six, F_2-derived F_6 near-isolines for either the 1BL.1RS or 1AL.1RS wheat–rye translocation were developed at the University of Missouri from three released cultivars and two experimental lines that were selected because they (i) were genetically diverse based on pedigree, (ii) occupied major acreage in the Midwest, or (iii) had a wide range of milling-quality and baking-quality attributes. Genetic backgrounds included 'Caldwell' (Patterson et al., 1982); 'Becker' (Lafever, 1988); and 'Pioneer Variety 2551', developed by Pioneer Hi-Bred International (Windfall, IN) and released in 1985; and MO 10501 and MO 11728, developed by the University of Missouri Agricultural Experiment Station. The hard red spring wheat 'Glennson 81', developed by the Center for Maize and Wheat Improvement (CIMMYT), was used as the donor of the 1BL.1RS translocation derived from Kavkaz. The hard red winter wheat Amigo was the donor of the 1AL.1RS translocation (Sebesta et al., 1995).

A conventional backcrossing program was initiated in 1988 and terminated in 1992 with the backcross-six generation. Root-tip samples were collected from F_1 seedlings from each backcross generation and individually C-banded according to Lukaszewski and Gustafson (1983) to identify progeny heterozygous for either translocation. After six backcrosses, heterozygous progeny were selected, self-pollinated, and screened again for the presence of the translocation. Four F_2 progeny from each cross, homozygous for the presence or absence of the translocation, were increased and advanced to the F_6 in the glasshouse.

Evaluation of Milling and Baking Quality

Within each of the five genetic backgrounds, 16 isolines were evaluated for milling and baking quality: four lines with and four lines without either the 1BL.1RS or 1AL.1RS translocation. A randomized complete block design was used with treatments in a split-plot arrangement. Genetic backgrounds were the whole plots and isolines were the subplots. The experiment was replicated four times and grown on Tiptonville silt loam soil (fine-silty, mixed, thermic Oxyaquic Argiudolls) at Columbia, MO, in 1995, and on Mexico silt loam soil (fine, smectitic, mesic Aeric Vertic Epiaqualfs) at Portageville, MO, in both 1995 and 1996. Entries were sown in six-row plots, 4.6 m long with 17.8 cm row spacing, at a constant plant density of 379 seeds m^{-2}. All plots were trimmed to 3.9 m for harvest.

Plots were harvested with a combine at maturity. Grain samples (100 g) were analyzed at the USDA-ARS Soft Wheat Quality Laboratory, Wooster, OH, for milling and baking quality. Shriveled seeds were removed from each sample before analyses. The amount of shriveled seed removed from each 100-g sample was comparable across genetic backgrounds and isolines. Adjusted flour yield and softness equivalent were determined according to Finney and Andrews (1986). The milling-quality score was expressed as the deviation (percentage units) from the nursery standard Caldwell of a weighted composite score of flour yield (50%) and softness equivalent (50%). Flour protein content and moisture content were estimated by near infrared reflectance spectroscopy according to Williams (1979) and Williams et al. (1982). Alkaline water-retention capacity was determined according to Yamazaki et al. (1968). Baking quality was expressed as the deviation (percentage units) from Caldwell of a weighted composite score of AWRC (50%) and softness equivalent (50%). Composite scores for both milling and baking quality are in accordance with standard microtest procedures of the USDA-ARS Soft Wheat Quality Laboratory.

Preliminary analyses indicated no significant differences among the four near-isolines within each genetic background–isoline combination, therefore, data for each group of four near-isolines were averaged for analyses of these effects. Analyses of variance were performed on data from each environment separately. Homogeneity of error variances was tested according to Gomez and Gomez (1984, p. 467–469). Error variances were homogeneous for most traits in the three environments sampled; however, the error variance for softness equivalent in the Portageville environment in 1996 (0.2100) was approximately half that in either of the environments in 1995 (0.4045 and 0.4413 for Portageville and Columbia, respectively). Because of the size of the difference, we did not consider transformation necessary and therefore combined data across environments for analyses. Statistical analyses were performed according to a split-plot design outlined by Cochran and Cox (1957). All effects, except replications within environments, were considered fixed. Variation among line means was partitioned into translocation source (1AL.1RS vs. 1BL.1RS) and isolines (presence or absence of the rye translocation). *F*-tests were constructed for genetic background and environment × genetic background using the replicate within environment × genetic background mean squares. The effects of translocation source and presence or absence of rye (isolines) were tested with the pooled subplot error. Means comparisons were conducted using Fisher's least significant difference at the $P = 0.05$ probability level.

RESULTS AND DISCUSSION

Milling Quality

The effects of genetic background, environment, and their interactions were significant ($P = 0.01$) for adjusted flour yield, softness equivalent, and the milling-quality composite score (Table 1). Analysis of subplot effects indicated highly significant effects of both the presence of the 1RS translocation (isoline) and the translocation source (1BL.1RS vs. 1AL.1RS) on all milling-quality traits measured. All first-order interactions were significant as were the second-order interactions with genetic background and environment.

Milling quality reflects the intrinsic value of wheat to the miller. As little as a 1% increase in milling quality, particularly in the adjusted flour yield from a set volume of grain, represents a significant improvement in milling quality. The Portageville location in both 1995 and 1996 produced grain with better milling quality than the Columbia location. Over the three environments of testing, milling-quality scores across backgrounds and isolines ranged from a high of 90.6% at Portageville in 1996 to a low of 87.1% at Columbia in 1995. Adjusted flour yield ranged from 712 g kg^{-1} to 701 g kg^{-1} while softness equivalent ranged from 61.1 to 55.8% for these two environments, respectively. For the Portageville environment in 1995, milling quality, adjusted flour yield, and softness equivalent were 87.3%, 703 g kg^{-1}, and 55.6%, respectively.

Mean milling-quality scores of rye and non-rye isolines, averaged across backgrounds and environments, are presented in Fig. 1a. No significant difference was observed between non-rye isolines derived from the Glennson 81 (1BL.1RS) or Amigo (1AL.1RS) sources of 1RS. This suggests that six backcrosses were sufficient to recover milling quality in the genetic backgrounds studied. Across genetic backgrounds, the average effect of 1BL.1RS on milling quality was not significant, while 1AL.1RS was associated with a significant reduction in milling quality when averaged over backgrounds.

Although the mean effect of 1BL.1RS was not significant, the effect of this translocation on milling quality varied significantly with genetic background (Fig. 2). In three backgrounds, 1BL.1RS was associated with a significant reduction in milling quality, while in Becker it increased milling quality and in MO 10501 it had no effect. For all backgrounds except MO 10501, the presence of 1AL.1RS was associated with a significant reduction in milling quality. In Becker, Caldwell, and Pioneer Variety 2551, the reduction was greater than that associated with the 1BL.1RS translocation. MO 11728 had the highest milling quality of any background investigated. In this background, the reduction in milling quality associated with both sources of 1RS was offset by the fact that this background had such high milling quality. Milling quality of 1RS isolines in this back-

Table 1. Mean squares for milling and baking quality traits of rye and non-rye near-isogenic lines for either the 1AL.1RS or 1BL.1RS translocation in five genetic backgrounds over three environments, 1995–1996. Data are based on the means of four isolines per subplot treatment.

Source	Degrees of freedom	Adjusted flour yield†	Softness equivalent	Milling quality‡	Flour protein	AWRC§	Baking quality‡
Main plot							
Environment (E)	2	29.6**	796.1**	315.0**	70.1**	8.7**	677.6**
Replicate within E	9	0.8	5.9	8.8	0.3	1.7	11.6
Genetic background (BG)	4	23.5**	452.2**	249.7**	10.7**	44.6**	477.1**
BG × E	8	5.7**	13.9**	60.4**	1.9**	10.1**	131.8**
Replicate within BG × E	36	0.3	1.7	3.2	0.3	0.7	4.7
Subplot							
Translocation source (TS)	1	12.8**	18.0**	136.2**	0.5*	13.4**	128.4**
Isoline¶	1	14.0**	291.3**	148.7**	4.4**	90.5**	1233.2**
BG × TS	4	4.1**	7.9**	43.6**	0.1	5.0**	40.8**
BG × isoline	4	2.0**	13.7**	21.6**	0.3**	1.1**	14.4**
TS × isoline	1	8.8**	18.1**	94.2**	0.1	7.7**	93.3**
BG × TS × isoline	4	1.2**	9.1**	13.0**	0.1	1.7**	27.2**
TS × E	2	0.8**	2.1*	8.4**	0.1	0.2	4.3
BG × TS × E	8	0.2*	2.6**	2.4**	0.2*	0.4	7.3**
Isoline × E	2	0.5**	2.0**	5.4**	0.1	1.9**	16.1**
BG × isoline × E	8	0.6**	1.7**	6.0**	0.1	0.5	2.9
Isoline × TS × E	2	0.3**	2.6*	3.7*	0.2	0.1	3.0
BG × isoline × TS × E	8	0.3**	0.7	3.2**	0.0	0.4	2.2
Pooled error	135	0.1	0.6	1.1	0.1	0.2	1.7
Total	239						
CV, %		0.5	1.4	1.2	2.8	0.9	1.4

* indicates significance at $P = 0.05$.
** indicates significance at $P = 0.01$.
† Flour yields adjusted to 14% moisture and 52% softness equivalent according to the testing procedures of the Soft Wheat Quality Lab., Wooster, OH.
‡ Expressed as a value relative to the nursery quality standard, Caldwell.
§ AWRC = alkaline water-retention capacity.
¶ Near-isolines with or without the 1AL.1RS or 1BL.1RS translocation.

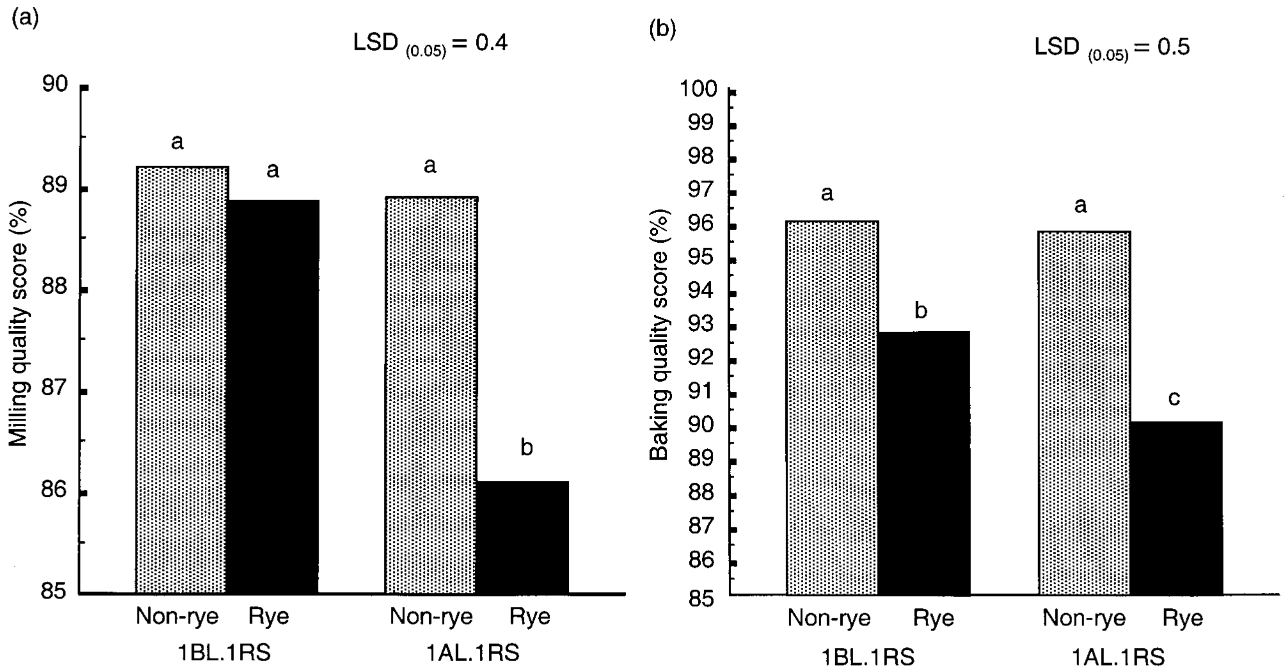

Fig. 1. Milling-quality (a) and baking-quality (b) score means of rye and non-rye near-isogenic lines for the 1BL.1RS or 1AL.1RS translocation averaged across five genetic backgrounds over three environments, 1995–1996. For each trait, means with different letters are significantly different, based on the respective LSD.

ground exceeded milling-quality scores of non-rye isolines in all other backgrounds. This suggested that although these translocations reduce milling quality in some backgrounds, selection within good genetic backgrounds can lead to genotypes with acceptable milling quality even when the translocation is present.

Milling quality is assessed as a composite score of adjusted flour yield and softness equivalent. Analyses of both components indicated that the observed effect of 1RS on milling quality, where significant, was due primarily to a reduction in kernel softness. Data for adjusted flour yield across genetic backgrounds (Fig. 3a) mirrored milling quality, while those for softness equivalent (Fig. 3b) indicated a significant reduction in

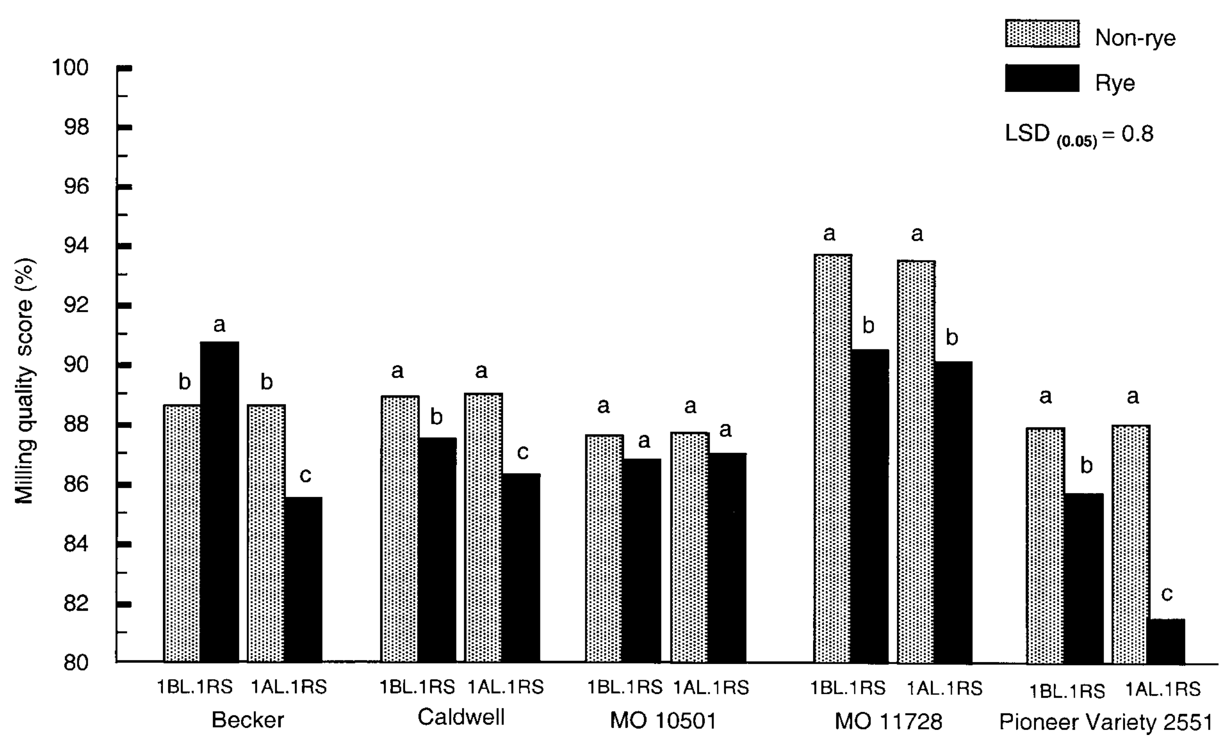

Fig. 2. Milling-quality score means of 1BL.1RS or 1AL.1RS near-isogenic lines in five soft red winter wheat genetic backgrounds over three environments, 1995–1996. Within each genetic background, means with different letters are significantly different, based on the LSD.

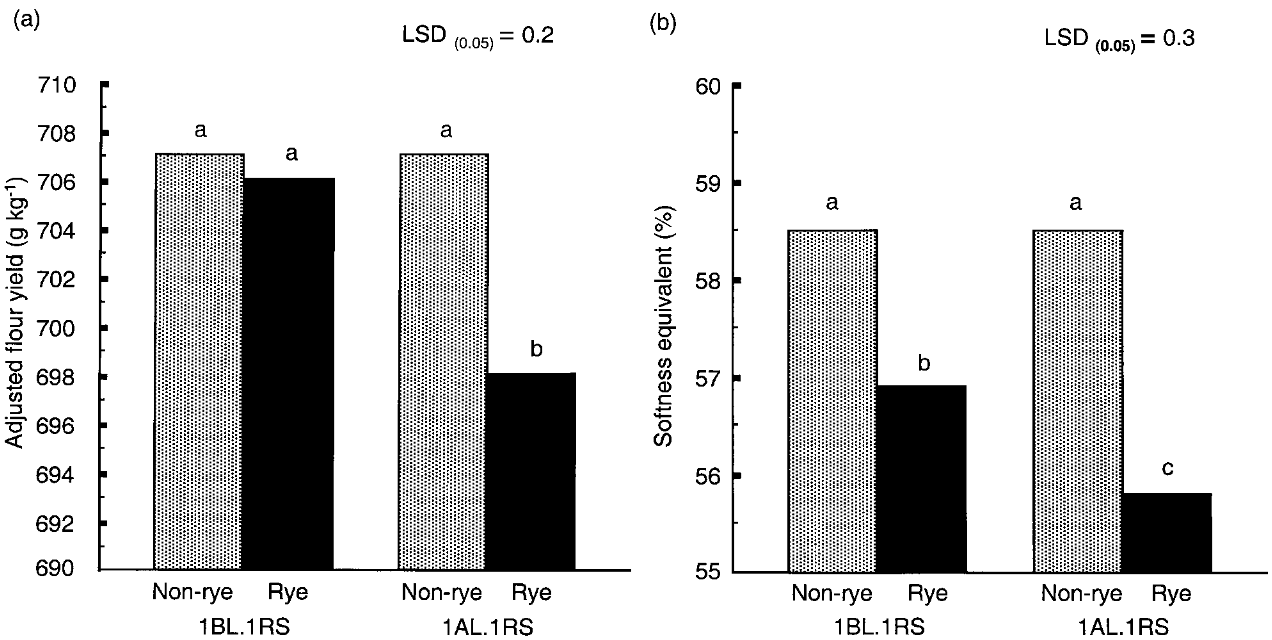

Fig. 3. Adjusted flour yield (a) and softness (b) equivalent means of rye and non-rye near-isogenic lines for the 1BL.1RS or 1AL.1RS translocation averaged across five genetic backgrounds over three environments, 1995–1996. For each trait, means with different letters are significantly different, based on the respective LSD.

softness due to both sources of 1RS. The reduction associated with 1AL.1RS was more detrimental than that associated with 1BL.1RS. Interaction effects were clear when data from individual genetic backgrounds were examined. In Caldwell, MO 11728, and Pioneer Variety 2551, flour yield was reduced by the presence of 1RS while there was no effect of 1RS in MO 10501 (Fig. 4), and flour yield was enhanced by 1BL.1RS in Becker. In three of the five backgrounds, the reduction of milling quality associated with 1AL.1RS was significantly greater than that associated with 1BL.1RS.

The effects of 1RS on softness equivalent were more consistent across genetic backgrounds (Fig. 5). In four of five backgrounds, 1RS was associated with a significant reduction in kernel softness. The presence of 1AL.1RS had a significantly greater effect than 1BL.1RS in three

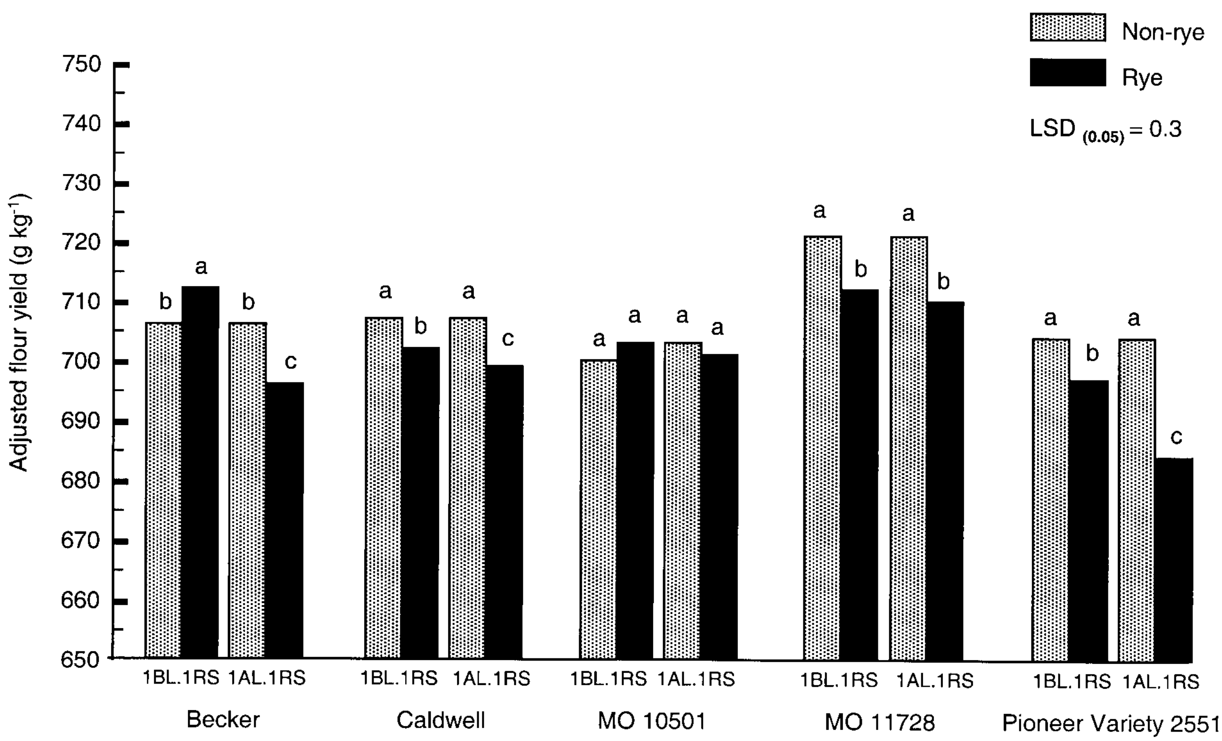

Fig. 4. Adjusted flour yield means of 1BL.1RS or 1AL.1RS near-isogenic lines in five soft red winter wheat genetic backgrounds over three environments, 1995–1996. Within each genetic background, means with different letters are significantly different, based on the LSD.

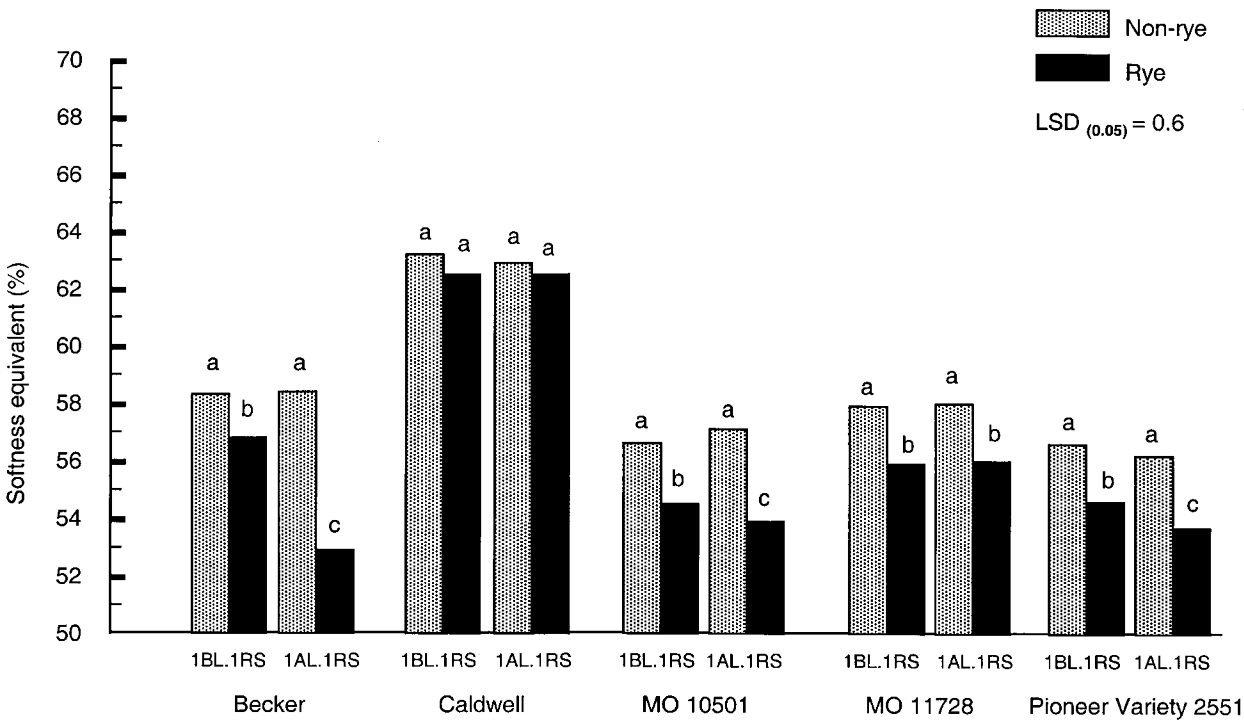

Fig. 5. Softness equivalent means of 1BL.1RS or 1AL.1RS near-isogenic lines in five soft red winter wheat genetic backgrounds over three environments, 1995–1996. Within each genetic background, means with different letters are significantly different, based on the LSD.

of these genetic backgrounds. Neither translocation, however, had a significant effect on kernel softness in Caldwell, and translocated lines were softer than non-rye lines in all other backgrounds.

The effects of 1RS on milling quality have not been widely reported in either hard or soft wheat. In hard wheat, no significant effects of 1BL.1RS on flour yield, softness, or milling quality were observed (Dhaliwal et al., 1987; Fenn et al., 1994) while in soft red winter wheat, 1BL.1RS was often associated with reductions in milling quality and flour yield (McKendry et al., 1996; Johnson et al., 1999). Both McKendry et al. (1996) and Johnson et al. (1999) found some backgrounds containing the translocation had higher flour yields and milling quality than backgrounds without the translocation, suggesting careful selection of genetic background could ameliorate the negative effect of 1RS on milling quality. The results of this study, which had a wider range of genetic backgrounds, concur with previous findings. Data from these genetic backgrounds, however, suggested that 1BL.1RS would be a better mechanism for introducing rye genes into soft wheat because its effect on milling quality was less pronounced than that of 1AL.1RS.

Baking Quality

Highly significant effects of genetic background, the environment, and their interactions were detected for all traits associated with baking quality (Table 1). The effect of isoline and translocation source were also significant for all traits, although the effect on flour protein content was small relative to effects on other traits. For both AWRC and overall baking quality, all first-order interactions were significant except for the interaction of translocation source × environment. Second-order interactions appeared less important for these traits than for milling-quality traits. For flour protein content, interactions were significant only for genetic background × isoline and genetic background × translocation source × environment.

As was the case for milling quality, baking-quality composite scores across genetic backgrounds and isolines were highest for the Portageville environment in 1996. Over the three environments, mean baking-quality scores ranged from a high of 97% for Portageville in 1996 to a low of 91.5% for Columbia in 1995. Baking-quality scores for Portageville in 1995 averaged 92.5%. Neither AWRC nor flour protein content across genetic backgrounds and isolines varied significantly over environment. Alkaline water-retention capacity ranged from a low of 54.8% at Portageville in 1995 to a high of 55.4% at Columbia in 1995. At Portageville in 1996, the mean AWRC across all genetic backgrounds was 55.2%. Mean flour protein content across genetic backgrounds ranged from 97.4 g kg^{-1} at Portageville in 1996 to 105.6 g kg^{-1} at Columbia in 1995. The mean flour protein content across backgrounds at Portageville in 1995 was 101.0 g kg^{-1}. Finally, as noted earlier, the softness equivalent, which contributes 50% of the baking-quality composite score, was significantly higher in the Portageville environment.

Mean baking-quality scores in non-rye isolines derived from Glennson 81 did not differ significantly from those derived from Amigo (Fig. 1b). As was apparent with milling quality, these data suggested that following the transfer of 1BL.1RS and 1AL.1RS, respectively,

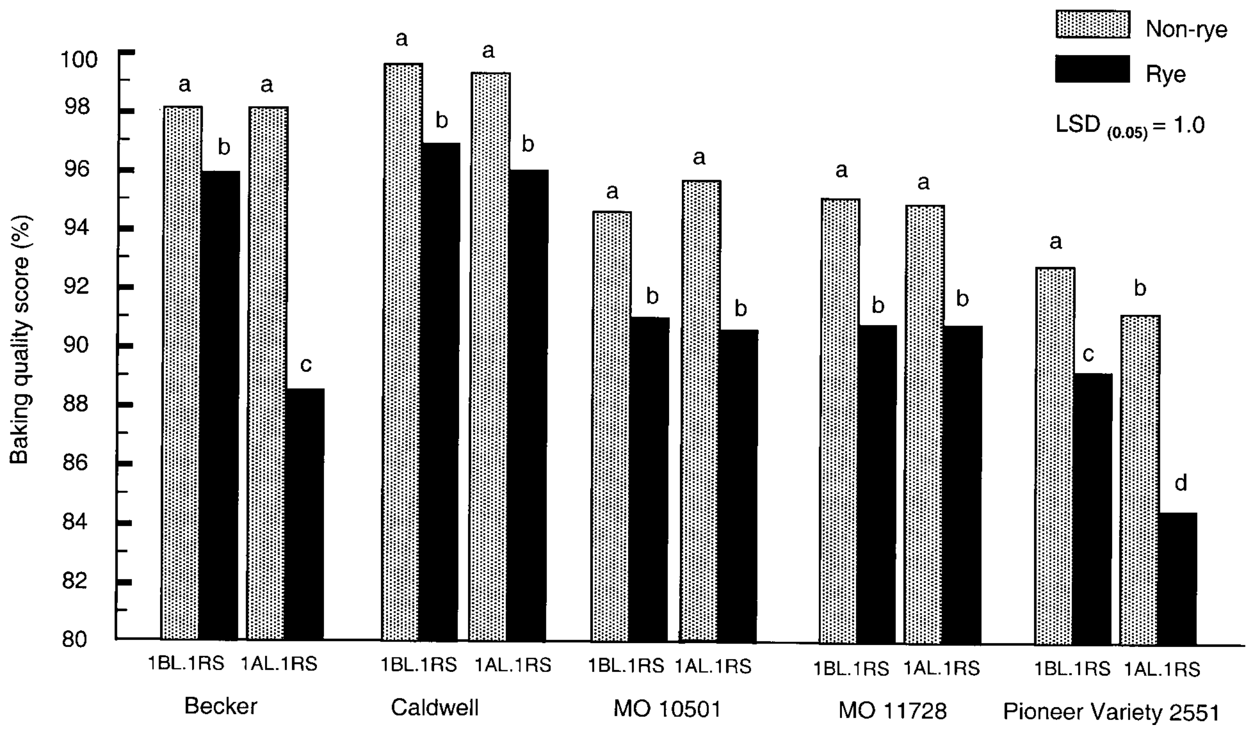

Fig. 6. Baking-quality score means of 1BL.1RS or 1AL.1RS near-isogenic lines in five soft red winter wheat genetic backgrounds over three environments, 1995–1996. Within each genetic background, means with different letters are significantly different, based on the LSD.

genetic backgrounds were adequately recovered. We concluded, therefore, that the effects observed due to the presence of 1RS were independent of genetic background. A negative effect of both sources of 1RS on baking quality was observed, with the effect of 1AL.1RS being significantly more pronounced than that of 1BL.1RS. These data agree with the many published reports of the negative effect of 1BL.1RS on baking quality (Pena et al., 1990; Graybosch et al., 1993; Fenn et al., 1994; Hussain et al., 1997; Johnson et al., 1999), but were contrary to those of Graybosch et al. (1993), who found that the negative effect of 1BL.1RS on hard wheat quality was greater than that of 1AL.1RS.

When effects of 1RS were examined in individual backgrounds, it was again clear that observed effects were dependent on both the source of the translocation and the genetic background into which the translocation was placed (Fig. 6). For all genetic backgrounds, the presence of 1RS, regardless of source, resulted in a significant reduction in the baking quality. For two of the backgrounds studied, Becker and Pioneer Variety 2551, 1AL.1RS had a more adverse effect on baking quality than 1BL.1RS. This was true, despite the fact that recovery of the background for Pioneer Variety 2551 appeared to be less complete than that for other genetic backgrounds. It is important to note that for Caldwell and Becker—the best baking-quality backgrounds tested—the reduction associated with 1BL.1RS was alleviated by the superior quality of these genetic backgrounds. For both of these backgrounds, the baking quality of isolines carrying the 1BL.1RS translocation was equal or superior to that of other non-rye isolines. This level of genetic variability for the effect of 1BL.1RS has been previously reported (Fenn et al., 1994; Lee et al., 1995; Johnson et al., 1999) and suggests that breeders may be able to develop translocated varieties with acceptable baking quality if the 1BL.1RS translocation is introgressed into genetic backgrounds with good quality. This could also be the case for the 1AL.1RS translocation since the negative effect of this translocation was not consistently greater than that associated with 1BL.1RS. Specifically, data for Caldwell suggest improved baking quality in lines carrying the 1AL.1RS translocation can be identified by inserting the translocation into good genetic backgrounds.

In general, low water absorption (AWRC $<55\%$) and a high degree of kernel softness (softness equivalent $>60\%$) are desirable for good baking quality (Finney, 1990). The negative effect of 1RS on softness has been noted earlier. Across genetic backgrounds, the presence of 1RS also resulted in a significant increase in AWRC, with 1AL.1RS being associated with a significantly more pronounced adverse effect than 1BL.1RS (Fig. 7a). Hoseney et al. (1988) reported negative correlations ($r = -0.70$ to -0.85) between the AWRC value and the spread of cookies made with straight grade flours. The observed increase in AWRC associated with 1RS, therefore, would be detrimental to the use of these flours in cookies. This negative effect of 1RS was observed in most genetic backgrounds (Fig. 8), with the effect of 1AL.1RS being greater than that of 1BL.1RS in Becker, Caldwell, and Pioneer Variety 2551. For MO 10501 and MO 11728, the two sources of rye had a similar effect, while in the cultivar Becker, 1BL.1RS had no significant effect on AWRC. The negative effect of the translocation was offset in MO 10501 by the low AWRC values

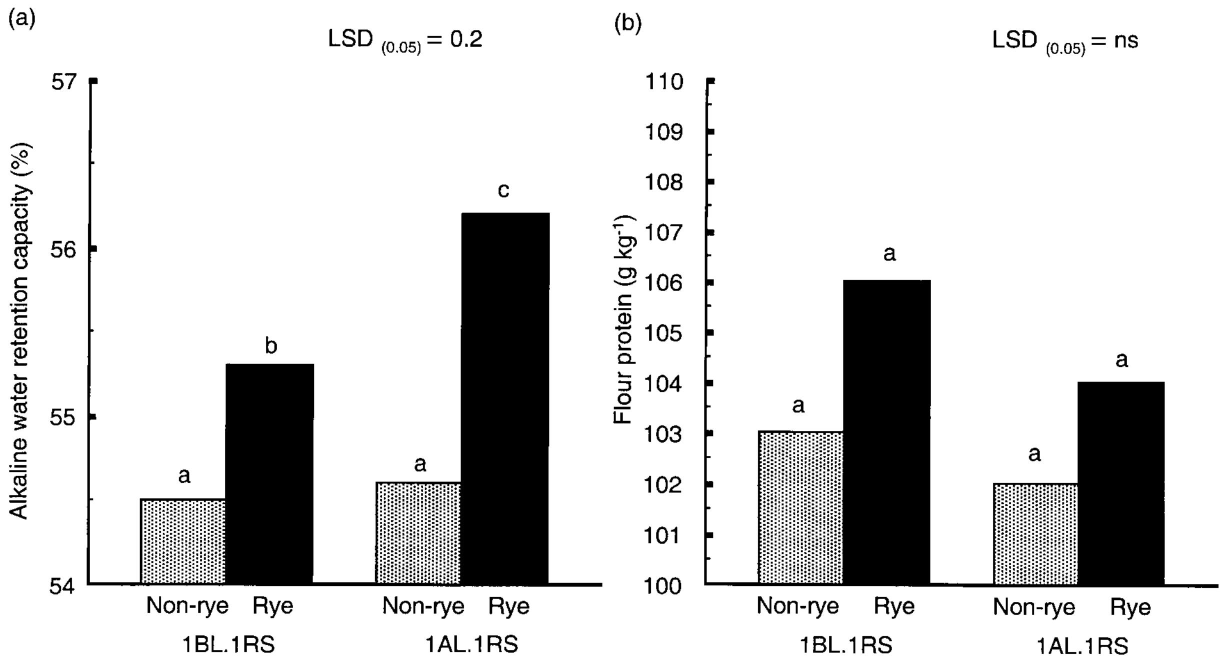

Fig. 7. Alkaline water-retention capacity (a) and flour protein content means (b) of rye and non-rye near-isogenic lines for the 1BL.1RS or 1AL.1RS translocation averaged across five genetic backgrounds over three environments, 1995–1996. For each trait, means with different letters are significantly different, based on the respective LSD.

in that genetic background, as evidenced by the result that isolines carrying the translocation had lower AWRC than non-rye isolines in other backgrounds. Our results for this trait agree with previous reports in both hard and soft wheat (Dhaliwal et al., 1987; Graybosch et al., 1993; Fenn et al., 1994; McKendry et al., 1996; Johnson et al., 1999).

Finally, low flour protein, although not part of the baking composite score, is also a desirable attribute of soft wheat flours. The presence of 1RS tended to increase protein content of the flour, but the increase was not significant for either source of the translocation (Fig. 7b). This effect was consistent across all genetic backgrounds and therefore effects within genetic back-

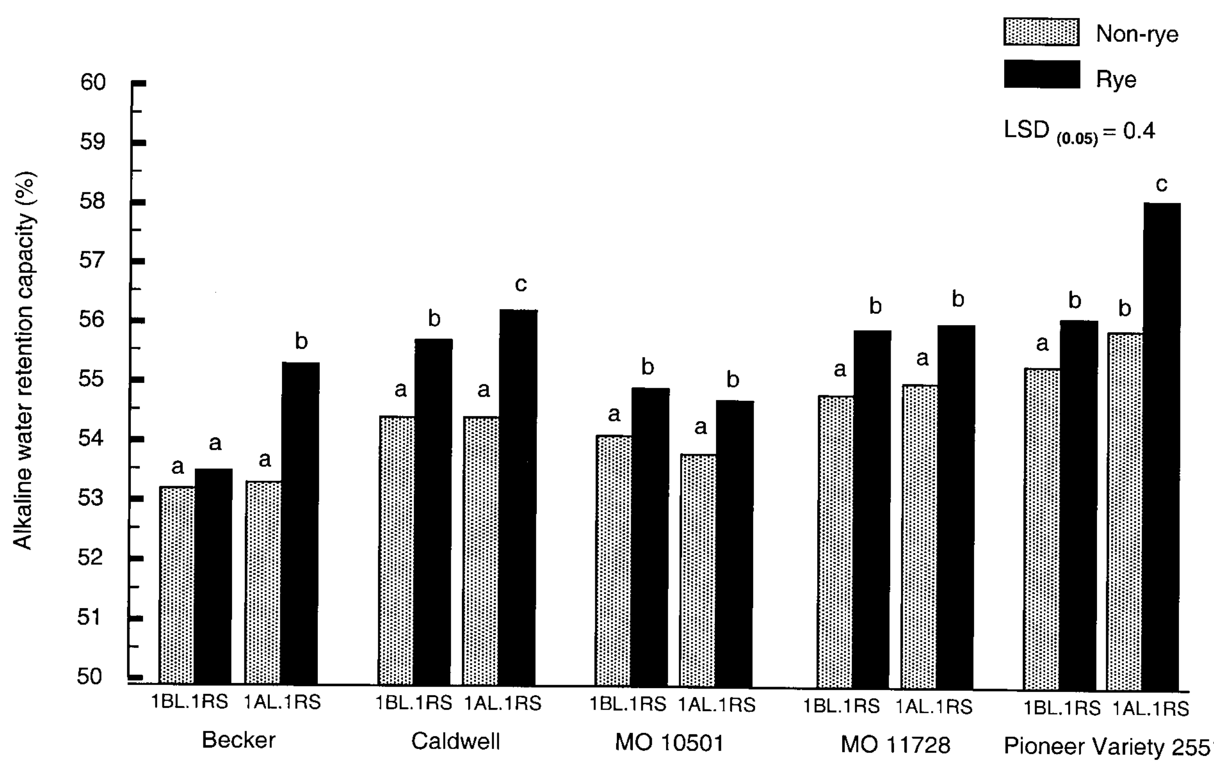

Fig. 8. Alkaline water-retention capacity means of 1BL.1RS or 1AL.1RS near-isogenic lines in five soft red winter wheat genetic backgrounds over three environments, 1995–1996. Within each genetic background, means with different letters are significantly different, based on the LSD.

ground have not been presented. This result was consistent with other results for soft red winter wheat (McKendry et al., 1996; Johnson et al., 1999) and for Australian soft biscuit wheat (Dhaliwal et al., 1987). Results for hard wheat have been varied. In some genetic backgrounds, 1BL.1RS was associated with a reduction in flour protein (Fenn et al., 1994), while in other backgrounds it increased flour protein (Lee et al., 1995). In still other backgrounds, no effect of either translocation on flour protein was observed (Dhaliwal et al., 1987; Graybosch et al., 1993).

In conclusion, both 1BL.1RS and 1AL.1RS reduced milling and baking quality in soft red winter wheat. This detrimental effect was due primarily to the negative effects these translocations had on both kernel softness and AWRC. Contrary to the work in hard wheat backgrounds, however, this research found the negative effect of 1AL.1RS to be greater than that of 1BL.1RS, suggesting that 1BL.1RS would be a better vehicle to introduce desirable genes from 1RS into this class of wheat. We also found that the choice of genetic background into which these translocations were inserted was critical to the magnitude of the effects of 1RS on end-use quality traits. In some genetic backgrounds, quality scores were high enough that the negative effects of 1RS were ameliorated, and isolines containing 1RS had higher milling-quality and baking-quality traits than non-rye isolines. We concluded, therefore, that through careful selection of genetic background, it would be possible for breeders to develop soft red translocated winter wheat varieties that have both acceptable milling and baking quality and the benefits of the rye genes carried on 1RS.

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